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# ITI canceller for reading shingle-recorded tracks

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**Abstract**

Shingled magnetic recording attracts much attention as a new recording system for hard disk drive to make the narrower track than the writer-track-width. However, the issue for reading by a wider reader than the track width on the media remains, and the inter-track interference (ITI) from adjacent tracks causes the performance deterioration. To recover the performance, in this paper, we propose an ITI canceller for the reproduced waveform from shingle-recorded tracks, and evaluate the performance of the PRML channel.

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*Keywords:* Perpendicular magnetic recording, Shingled magnetic recording, Inter-track interference, ITI canceller, PRML channel.

## 1. Introduction

Shingled magnetic recording [1] attracts much attention as a promising recording method on the narrower tracks than the writer-track-width. The read-back waveform from the intended track is affected by the cross-talk from the adjacent tracks, and the R/W performance degrades. We propose an ITI canceller using cross-correlation to improve the quality of the input waveform to Viterbi detector, and evaluate the performance of PRML cannel employing the canceller by computer simulation.

## 2. R/W channel

Fig.1 and Fig.2 show the block diagram of PRML channel with ITI canceller and an example of shingle-recorded track pattern, respectively. In Fig.1, the input-data sequence $\{a_k\}$ is NRZ recorded on the perpendicular magnetic

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recording (PMR) media using the shingle-recording, and the reader with the same width of sensitivity as the writer traces the recorded tracks to read the recorded signal as shown in Fig.2. Therefore, the read back waveform is disturbed by ITI, and the performance degrades. Now, we look at the last-written track by shingle-recording. As the last-written track #1 is not overwritten, it keeps an original track width written by the writer. In this system, the last-written track #1 is first read. The reproducing waveform from the track #1 is equalized by the equalizer composed of a low-pass filter with a cut-off frequency $x_h$ normalized by the bit rate $f_b$ and a transversal filter with $N_t$ taps, where a PR1 [2] channel is adopted. Furthermore, the output-data sequence $\{\hat{a}_k\}$ is recovered from the equalized waveform by a Viterbi detector. Then, $\{\hat{a}_k\}$ is stored in the memory. Next, we assume that the track #2 is traced with ITI caused by the track #1. In order to recover the recorded data sequence, the ITI from the track #1 has to be reduced. The canceller reduces the ITI from the reproducing waveform of track #2 with ITI from track #1. As shown in Fig.2, the amounts of phase shift $\phi$ and ITI-amplitude ratio $\alpha$ between the replica of track #1 signal made by output-data sequence stored in the memory and the reproducing waveform from track #2 with ITI are estimated by their cross-correlation function over $L_c$ bits. The ITI signal replica is adjusted by phase and amplitude adjuster with $N_p$ taps, and is subtracted from the reproducing waveform from track #2.

We assumed that the isolated reproducing waveform at the reading point is $h(t) = A \tanh(\ln 3 / T_{50})\, t$, where $A$ and $T_{50}$ are the saturation level and the rising time from $-A/2$ to $A/2$ of $h(t)$, respectively [3]. The normalized linear density is defined by $K = T_{50} / T_b$ where $T_b$ is the bit interval. The noise at the reading point is assumed to be composed of a system noise and a jitter-like medium noise, and their powers in the bandwidth of $0.6f_b$ are represented by $\sigma_S^2$ and $\sigma_J^2$. The percentage of medium noise power to total noise power $\sigma = \sigma_S^2 + \sigma_J^2$ is defined by $R_J = \sigma_J^2 / \sigma \times 100$ [%]. The SNR at the reading point is also defined by SNR = $20\log_{10} A/\sigma$ [dB].

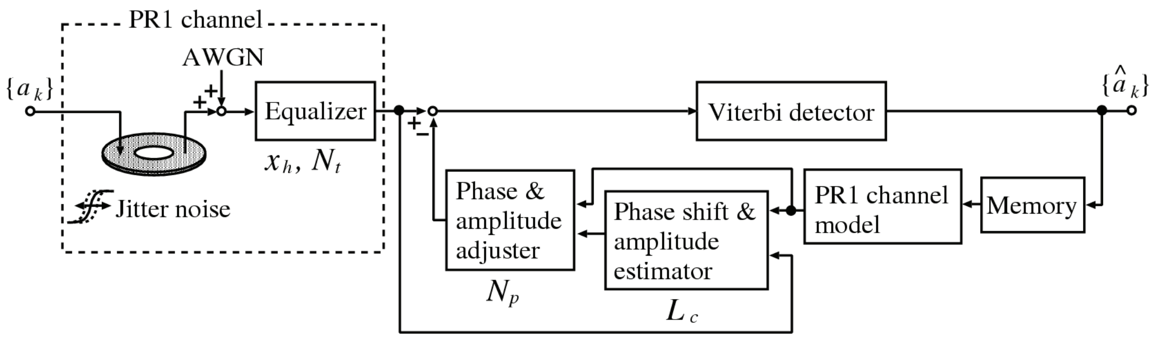



Fig. 1 Block diagram of ITI canceller system.

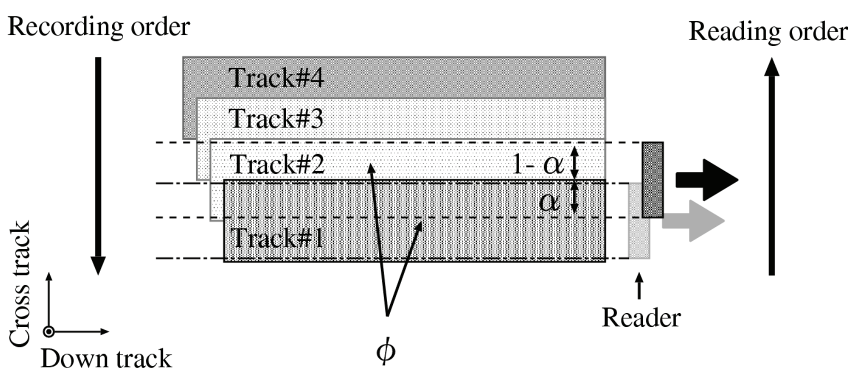



Fig. 2 Shingle-recorded track pattern.

**3. Phase shift and Amplitude estimation**

Fig. 3 shows an example of phase shift and ITI-amplitude estimation. In the figure, $\tau$ is delay time, and the symbol ○ and dashed line show the cross-correlation function between the output of PR1 cannel and the replica of the signal from the adjacent track and the approximated function using a quadratic function, respectively. The phase shift and amplitude estimator approximates the cross-correlation function using a quadratic function, and obtains the estimated phase shift $\hat{\phi}$ and estimated ITI-amplitude ratio $\hat{\alpha}$ from the peak position and peak value of the correlation function, respectively. Fig.4 shows the phase and amplitude adjuster which is constructed by a FIR filter, and the phase and amplitude of the signal model output is adjusted by the filter. In the figure, $D$ is the delay operator of a bit interval $T_b$ and $C_n$ ($n$ = 0, 1, ⋯, $N_p$-1) is the tap coefficients given by the following equation.

$$C_n = \hat{\alpha} \times \frac{\sin\{(n - N_p/2)\pi - \hat{\phi}\}}{(n - N_p/2)\pi - \hat{\phi}} \quad (1)$$

Fig. 5 shows the relationship between $\phi$ and $\hat{\phi}$. The parameters are set to $\alpha$ = 0.50, $K$ = 1.2, $R_J$ = 90 %, $x_h$ = 0.4, $N_t$ = 15, and $L_c = 2\times10^3$. The symbols ○, □ show characteristics at SNR = 18 and 22 dB, respectively. As can be seen from the figure, the phase shift values are successfully estimated for either SNR. Fig.6 shows the relationship between $\alpha$ and $\hat{\alpha}$. The parameters are set to $\phi$ = 0.20, $K$ = 1.2, $R_J$ = 90 %, $x_h$ = 0.4, $N_t$ = 15, and $L_c = 2\times10^3$. The symbols ○, □ show characteristics at SNR = 18 and 22 dB, respectively. As can be seen from the figure, the amplitude is also estimated successfully.

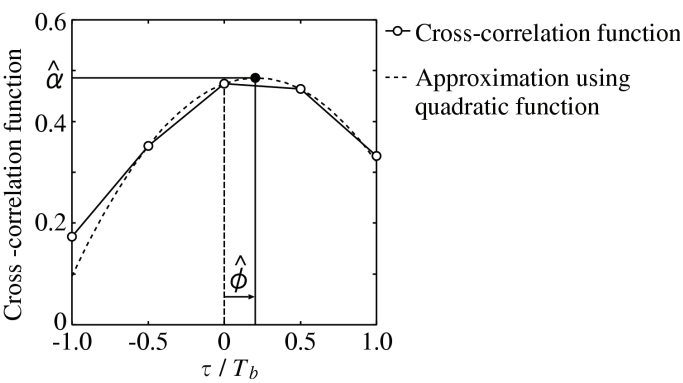



Fig. 3 ITI-amplitude and phase shift estimation.

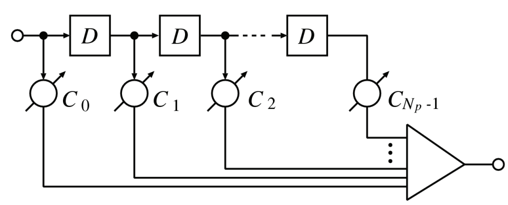



Fig. 4 Phase and amplitude adjuster.

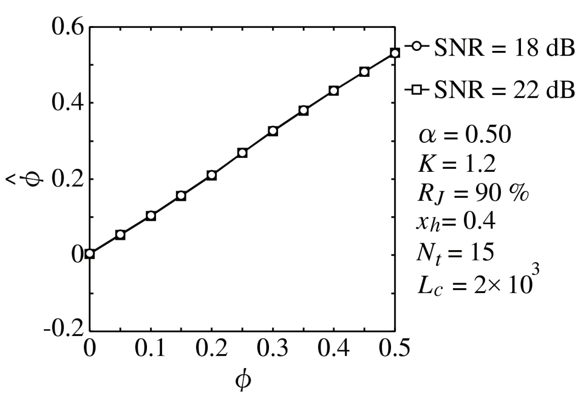



Fig. 5 Estimated phase shift.

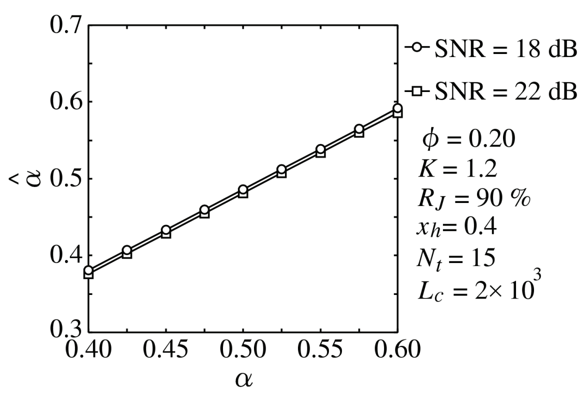
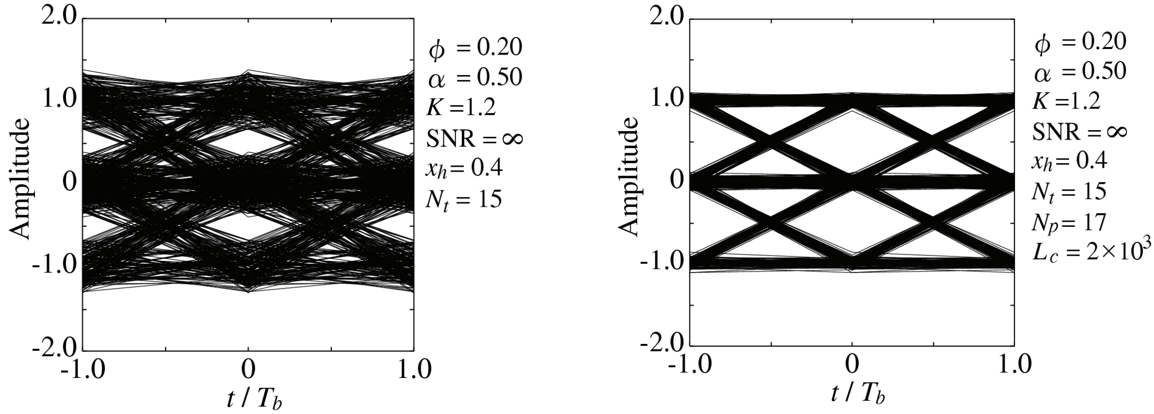



Fig. 6 Estimated ITI-amplitude ratio.

## 4. Performance comparison

Fig.7 shows the eye patterns at the Viterbi detector input, where (a) and (b) show the improved eye patterns by ITI cancelling without and with the adjuster, respectively. The parameters are set to $\phi$ = 0.20, $\alpha$ = 0.50, $K$ = 1.2, SNR = $\infty$, $x_h$ = 0.4, $N_t$ = 15, $N_p$ = 17, and $L_c$ = $2 \times 10^3$. As can be seen from the figure, ITI is well cancelled by using the adjuster.

Fig.8 shows the BER performance of PR1ML system with an ITI canceller. The parameters are also set to $\phi$ = 0.20, $\alpha$ = 0.50, $K$ = 1.2, $R_J$ = 90 %, $x_h$ = 0.4, $N_t$ = 15, $N_p$ = 17, and $L_c$ = $2 \times 10^3$. The symbols ○, □ and △ show the performance of PRML systems with an ITI canceller using both amplitude and phase adjustments, with an ITI canceller having no adjustment, and without canceller, respectively. As can be seen from the figure, while most data sequence can not be recovered without the ITI canceller due to ITI from the adjacent track, the ITI canceller can significantly cancel the ITI and improves the BER performance of PRML system. We can see that the ITI cancellation with phase and amplitude adjustment attain the further improvement in the performance.




(a) With ITI canceller without adjuster (b) With ITI canceller using adjuster

Fig. 7 Eye pattern of Viterbi detector input.

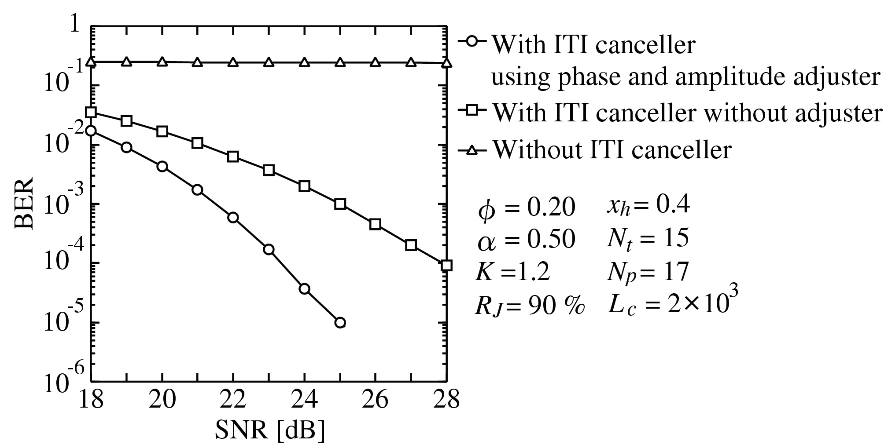



Fig. 8 BER performance.

## 5. Conclusions

We proposed an ITI canceller for the reproduced waveform from shingle-recorded tracks, and evaluated the performance of PRML system with the ITI canceller. The results show that our ITI canceller is efficient to read the shingle-recoded tracks.

## Acknowledgments

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